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The 2002 Leonid MAC Airborne Mission - First Results.

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Abstract. The NASA and USAF sponsored 2002 Leonid Multi-Instrument Campaign consisted of two instrumented aircraft that flew from Madrid, Spain, to Omaha, Nebraska, with 38 researchers on board to cover the two Leonid storm peaks. Both aircraft were above clouds and under perfect observing conditions, with a radiant climbing from 35 to 67 degree elevation and the full Moon relatively low in the sky. All instruments worked as expected and aurora, moon, and meteors made the view scenic and truly spectacular at times. This report is a brief impression of the mission and a first look at some of the results in the weeks following the campaign.

1. Introduction

In the 2002 Leonid Multi-Instrument Aircraft campaign, we had the privilege to use the NASA DC-8 Airborne Laboratory for meteor storm research, in a stereoscopic viewing with the USAF/FISTA aircraft used in earlier missions [1-8]. This was our fourth and final mission as part of the Leonid MAC program and offered a team of 38 researchers from 7 different countries a chance to see the 2002 Leonid storms under ideal observing conditions. By following a westward trajectory from Madrid (Spain) to Omaha (Nebraska), we were able to have a 10-hour night in which the Leonid radiant rose from 35 degrees at the onset to 67 degrees just before landing. Moreover, the near-full Moon was relatively low in the sky near the nose of the planes.

Figure 1 - The DC-8 "Airborne Laboratory" aircraft crew and scientists (photo Eric James).

2. Experiments

At Torrejon de Ardoz, near Madrid, we were hosted by the *Centro de Astrobiologia* (CAB) of director Juan Perez-Mercader. Three CAB participants operated one of many instruments on the DC-8 aircraft. Those instruments included the German University of Bremen sub-mm spectrometer "ASUR" that measured repeatedly during flight NO, O_3, HCl, HCN and H_2CO, in search of variations of the abundance of upper atmosphere molecules from the increased influx of meteoroids or their effect on the atmosphere. In the same direction, a fiber-optic coupled slit-spectrograph of the University of East Anglia (UK) measured OH, Na, and O_2 airglow at optical wavelengths, while a near-IR InGaAs camera from Utah State University imaged the OH airglow. The USU team also filmed meteors through narrow-band filters. Three high-resolution spectrographs targeted the near-UV (using high-definition TV detection - ISAS, Japan), the visible region (SETI Institute) and the near-IR (CAB), the latter using unintensified cooled CCD cameras. A prototype automatic rapid pointing "AIMIT" meteor tracker was operated by George Varros, as a technology demonstration in a project with Peter Gural and the author.

Figure 2 - The NCK-135 "FISTA" aircraft crew and scientists (photo courtesy Eric James).

In addition, a team of eight amateur astronomers counted the meteors detected by window-mounted intensified cameras using a video headset display. An automatic tool developed by Chris Crawford and Mike Koop took a tally of the counts, which were analyzed, displayed, and transmitted in the form of brief one-line e-mails via globalstar satellite uplink by interactive software developed and operated by Morris Jones. This provided near-real time counts to satellite operators. The flux measurement team consisted of meteor observers Chris Crawford, Peter Gural, David Holman, Morris Jones, Jane Houston-Jones, Bob Lunsford, David Nugent, and Ruediger Jehn. The latter representing ESA, who helped distribute the counts.

For the first time, FISTA was equipped with "sticky tape", a dust collector from the University of New Mexico at Albuquerque in an attempt to gather meteoric debris from the first storm peak in the hours after the storm. The FISTA aircraft also deployed a 3-5.5 micron mid-IR spectrograph "MIRIS", capable of taking images and spectra of meteors and of persistent trains in search of the 3.4 micron band of complex organic molecules in meteoroids. In addition, FISTA deployed low-resolution slit-less spectroscopic techniques at ultraviolet (Rick Rairden, Lockheed Palo Alto) and optical wavelengths (Jiri Borovicka, Ondrejov Observatory, Czech Republic). Kristina Smith operated two Digital Array-Scanned Interferometer (DASY) spectrographs as a technology demonstration. A third spectrograph (SETI Institute) recorded low resolution spectra of intrinsically faint meteors on high-definition TV (NASA Ames) for measurements of meteoroid composition. Finally, Ian Murray of the Canadian University of Regina performed a study of meteor lightcurves and meteoroid morphology, completing an airborne dataset covering 1998-2002, complemented by photometric studies of Hans Stenbaek-Nielsen on the DC-8.

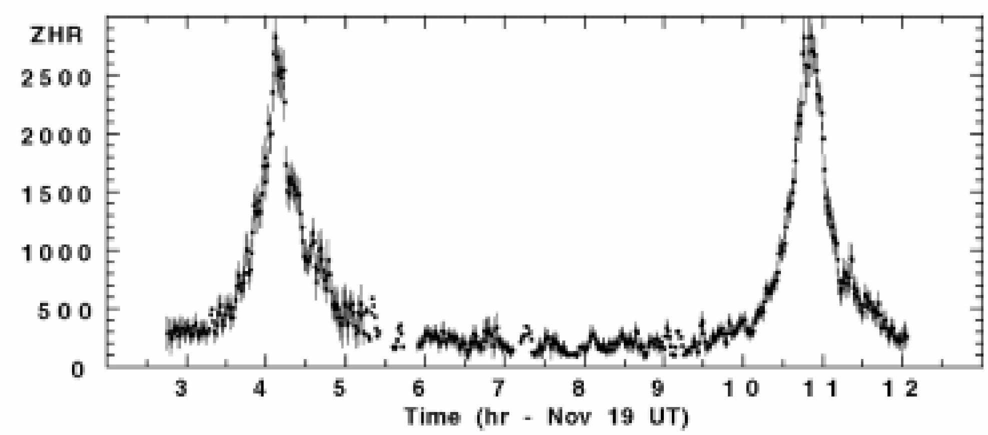

Figure 3 - Summary of 1-minute meteor counts (courtesy Leonid MAC flux measurement team).

3. Results
3.1 Near-real time flux measurements

The Leonid meteor storms occurred much as predicted. European observers saw the peak at 04:06 UT (ZHR ~ 2,300/hr - scaled to early IMO results [9]), while observers in the America's witnessed a storm peaking at 10:47 UT (ZHR ~ 2,600/hr). Times are corrected for topography [10]. Both peaks were narrow, with a full-width-at-half-maximum of only 0.52 and 0.50 hours, respectively. And both peaks were rich in faint meteors. Preliminary results from 1-minute counts (with a 3-point average and given in 2-minute intervals) are presented in Table I and Figure 3. They show a very precise slightly asymmetric Lorentz-shaped flux profile with no obvious filamentary structure or sub-peaks. A high background of activity persisted between the two storm peaks. That background may reflect the 1833 dust trail encounter (Lyytinen's prediction put the encounter time at 06:36 UT [11]). However, the high rates before the first storm peak and gradual decline during the observing period suggests that this is a manifestation of the Leonid Filament [12], peaking before 03 UT. Indeed, the magnitude distribution index was measured to be smaller between the storms: $r = 1.7 \pm 0.3$, versus a storm value of $r = 2.1 \pm 0.3$. These values will be improved upon further analysis. Also the absolute scale of the flux measurements is still uncertain. The near-real time data had peak rates of 1,000/hr and 1,400/hr, respectively. Similar data from visual observations by Jim Richardson and a team of observers at Mount Lemmon Observatory puts the peak ZHR of the 2nd storm as low as 800/hr, with pre-storm $r = 2.5$ versus a storm value of $r = 3.5$, respectively. A further improvement of results is expected when the sky limiting magnitude and r have been studied in more detail, and when also the FISTA intensified video camera tapes (operated by Mike Koop) have been examined.

Time(hr) 02 Nov 19	Sol long (J2000)	ZHR (/hr)	+/- (/hr)	Time(hr) 02 Nov 19	Sol long (J2000)	ZHR (/hr)	+/- (/hr)	Time(hr) 02 Nov 19	Sol long (J2000)	ZHR (/hr)	+/- (/hr)	Time(hr) 02 Nov 19	Sol long (J2000)	ZHR (/hr)	+/- (/hr)
2.767	236.5580	284	99	4.950	236.6497	365	83	7.467	236.7554	136	41	09.567	236.8437	175	32
2.800	236.5594	253	108	4.983	236.6511	546	110	7.500	236.7569	221	47	09.600	236.8451	250	36
2.833	236.5607	292	56	5.017	236.6525	355	76	7.533	236.7583	248	40	09.633	236.8465	238	40
2.867	236.5621	336	52	5.050	236.6539	496	73	7.567	236.7597	188	43	09.667	236.8479	261	33
2.900	236.5636	257	69	5.083	236.6553	533	76	7.600	236.7611	195	45	09.700	236.8493	282	36
2.933	236.5650	332	67	5.117	236.6567	345	74	7.633	236.7625	216	58	09.733	236.8507	328	39
2.967	236.5664	304	58	5.150	236.6581	309	93	7.667	236.7639	185	56	09.767	236.8521	203	31
3.000	236.5677	316	49	5.183	236.6595	539	108	7.700	236.7653	140	38	09.800	236.8535	285	39
3.033	236.5692	324	52	5.217	236.6609	293	72	7.733	236.7667	156	39	09.833	236.8549	354	52
3.067	236.5706	257	47	5.250	236.6623	462	163	7.767	236.7681	117	29	09.867	236.8563	275	33
3.100	236.5720	345	48	5.283	236.6637	261	92	7.800	236.7695	95	24	09.900	236.8577	297	39
3.133	236.5733	302	43	5.317	236.6651	456	161	7.833	236.7709	100	25	09.933	236.8591	335	41
3.167	236.5748	275	36	5.350	236.6665	520	184	7.867	236.7723	111	28	09.967	236.8605	397	38
3.200	236.5762	332	45	5.383	236.6679	324	115	7.900	236.7737	89	22	10.000	236.8619	395	39
3.233	236.5776	293	49	5.417	236.6693	291	103	7.933	236.7751	155	39	10.033	236.8633	314	38
3.350	236.5825	295	63	5.600	236.6770	169	42	7.967	236.7765	155	39	10.067	236.8647	322	31
3.383	236.5839	359	82	5.633	236.6784	168	42	8.000	236.7779	144	39	10.100	236.8661	271	34
3.417	236.5853	514	66	5.667	236.6798	318	79	8.033	236.7793	158	36	10.133	236.8675	376	34
3.450	236.5867	385	56	5.700	236.6812	280	70	8.067	236.7807	214	34	10.167	236.8689	438	42
3.483	236.5881	444	56	5.917	236.6903	175	33	8.100	236.7821	278	48	10.200	236.8703	434	41
3.517	236.5895	511	58	5.950	236.6917	200	33	8.133	236.7835	245	38	10.233	236.8717	507	41
3.550	236.5909	501	51	5.983	236.6931	217	38	8.167	236.7849	196	36	10.267	236.8731	559	53
3.583	236.5923	419	51	6.017	236.6945	297	38	8.200	236.7863	147	24	10.300	236.8745	625	52
3.617	236.5937	566	61	6.050	236.6959	273	36	8.233	236.7877	178	41	10.333	236.8759	652	53
3.650	236.5951	779	82	6.083	236.6973	231	37	8.267	236.7891	154	28	10.367	236.8773	680	47
3.683	236.5965	655	68	6.117	236.6987	294	40	8.300	236.7905	142	30	10.400	236.8787	732	53
3.717	236.5979	718	90	6.150	236.7001	251	40	8.333	236.7919	196	30	10.433	236.8801	805	59
3.750	236.5993	1000	101	6.183	236.7015	175	40	8.367	236.7933	136	21	10.467	236.8815	1022	68
3.783	236.6007	797	91	6.217	236.7029	302	43	8.400	236.7947	212	33	10.500	236.8829	993	61
3.817	236.6021	970	74	6.250	236.7043	227	31	8.433	236.7961	199	35	10.533	236.8843	1195	69
3.850	236.6035	1379	94	6.283	236.7057	224	33	8.467	236.7975	283	40	10.567	236.8857	1393	74
3.883	236.6049	1302	107	6.317	236.7071	265	39	8.500	236.7989	227	43	10.600	236.8871	1398	83
3.917	236.6063	1331	95	6.350	236.7085	219	38	8.533	236.8003	188	31	10.633	236.8885	1588	77
3.950	236.6077	1481	102	6.383	236.7099	260	39	8.567	236.8017	226	41	10.667	236.8899	1945	103
3.983	236.6091	1790	121	6.417	236.7113	184	37	8.600	236.8031	194	52	10.700	236.8913	2154	99
4.017	236.6105	1727	103	6.450	236.7127	161	49	8.633	236.8045	212	48	10.733	236.8927	2255	114
4.050	236.6119	1985	111	6.483	236.7141	217	44	8.667	236.8059	286	41	10.767	236.8941	2817	124
4.083	236.6133	2350	118	6.517	236.7155	145	29	8.700	236.8073	147	31	10.800	236.8955	2410	110
4.117	236.6147	2819	121	6.550	236.7169	139	59	8.733	236.8087	171	34	10.833	236.8969	2820	111
4.150	236.6161	2499	134	6.583	236.7183	180	55	8.767	236.8101	86	23	10.867	236.8983	2702	151
4.183	236.6175	2520	148	6.617	236.7197	280	51	8.800	236.8115	180	33	10.900	236.8997	2667	106
4.217	236.6189	2539	120	6.650	236.7211	204	41	8.833	236.8129	219	44	10.933	236.9011	2329	95
4.250	236.6203	1728	109	6.683	236.7225	164	35	8.867	236.8143	187	43	10.967	236.9025	2298	97
4.283	236.6217	1486	104	6.717	236.7239	155	42	8.900	236.8157	234	43	11.000	236.9039	1954	93
4.317	236.6231	1613	97	6.750	236.7253	307	62	8.933	236.8171	167	45	11.033	236.9053	1447	101
4.350	236.6245	1562	99	6.783	236.7267	299	68	8.967	236.8185	206	38	11.067	236.9067	1360	105
4.383	236.6259	1467	97	6.817	236.7281	281	85	9.000	236.8199	146	37	11.100	236.9081	1270	112
4.417	236.6273	1471	91	6.850	236.7295	175	75	9.033	236.8213	335	44	11.133	236.9095	1111	99
4.450	236.6287	1193	83	6.883	236.7309	315	72	9.067	236.8227	248	36	11.167	236.9109	1051	91
4.483	236.6301	941	81	6.917	236.7323	224	43	9.100	236.8241	104	26	11.200	236.9123	726	79
4.517	236.6315	899	73	6.950	236.7337	219	34	9.133	236.8255	96	24	11.233	236.9137	667	70
4.550	236.6329	933	72	6.983	236.7351	157	29	9.167	236.8269	297	74	11.267	236.9151	803	83
4.583	236.6343	1139	88	7.017	236.7365	162	37	9.200	236.8283	250	62	11.300	236.9165	705	85
4.617	236.6357	859	73	7.050	236.7379	147	24	9.233	236.8297	176	44	11.333	236.9179	763	86
4.650	236.6371	818	95	7.083	236.7393	123	28	9.267	236.8311	103	26	11.367	236.9193	908	87
4.683	236.6385	1009	111	7.200	236.7442	206	52	9.300	236.8325	145	36	11.400	236.9207	625	69
4.717	236.6399	821	111	7.233	236.7457	261	65	9.333	236.8339	116	29	11.433	236.9221	595	90
4.750	236.6413	663	80	7.267	236.7471	344	86	9.367	236.8353	217	38	11.467	236.9235	531	56
4.783	236.6427	909	123	7.300	236.7484	278	70	9.400	236.8367	172	27	11.500	236.9249	462	62
4.817	236.6441	645	74	7.333	236.7498	231	58	9.433	236.8381	121	23	11.533	236.9263	612	60
4.850	236.6455	495	80	7.367	236.7513	94	24	9.467	236.8395	352	49	11.567	236.9277	510	71
4.883	236.6469	535	102	7.400	236.7527	131	33	9.500	236.8409	284	54	11.600	236.9292	543	64
4.917	236.6483	417	80	7.433	236.7541	159	48	9.533	236.8423	156	42	11.633	236.9305	470	62

These observations provide important new data for dust trail models. The narrow flux profiles agree within error with the predicted duration of ~0.64 and 0.60 hrs [14], respectively, and demonstrate that the dust trails do not widen over time, as in the models by Lyytinen et al. (radiation pressure), Asher & McNaught, and Vaubaillon and Colas (a.o., from dynamic forces on dynamically different orbits). The strong showing of the 1767 dust trail relative to that of 1866 in Asher's model illustrates again that the trail positions are slightly further inward to the sun than calculated. The most important result may have been the high abundance of faint meteors. This is actually predicted in theoretical models, because the smaller grains are supposed to have the highest surface-to-mass ratio and therefore the strongest push from water drag during ejection and solar radiation pressure while in orbit. However, last year's shower did not show that effect. Hence, the distribution of meteoroid sizes in the trails is still poorly understood.

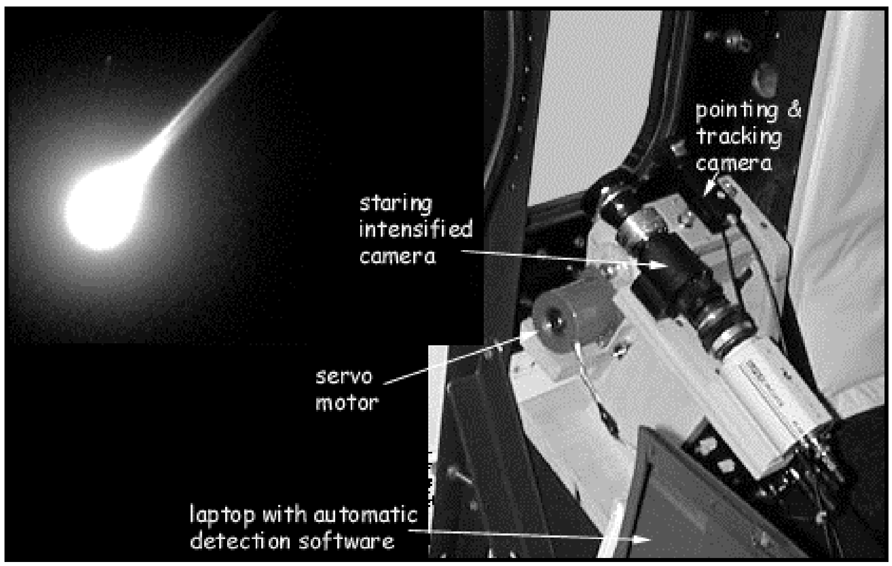

Figure 4 - Bright -8 magnitude 06:49:55 UT fireball tracked after automatic pointing (courtesy George Varros)

3.2 Spectroscopy and Imaging of meteors

Some other highlights include a tracked -8 magnitude Leonid fireball at 06:49:55 UT Nov. 17 (Figure 4). This and the tracking of many fainter meteors demonstrated for the first time that automatic rapid pointing to meteors is possible from aircraft. After a brilliant flash, the meteor re-appeared before burning out. A persistent train was visible for at least 4 minutes.

University of Alaska at Fairbanks researcher Hans Stenbaek-Nielsen operated a high-speed camera onboard the DC8 and recorded 59 meteors at 1000 frames/s. None was captured brighter than last year's "shocking Leonid" [8], but several fainter ones confirm the formation of a shock front, opening up not quite as wide (Figure 5). In addition, the peculiar diffuse high altitude beginning of two bright fireballs was captured (see inset Figure 5, lower left), a phenomenon discovered by Pavel Spurny and Hans Betlem during the 1998 campaign [13].

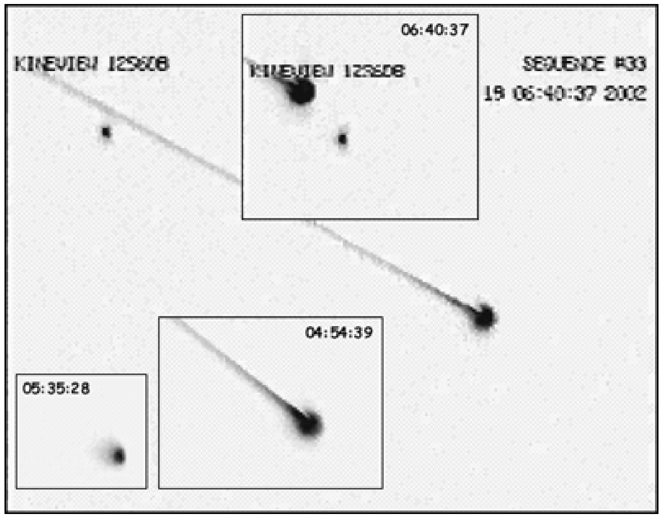

Figure 5 - Composite of high frame-rate images (courtesy Hans Stenbaek-Nielsen).

The SETI Institute cooled CCD spectrograph recorded some 40 optical spectra, twice the harvest from 2001. The instrument was operated by Emily Schaller of Caltech, who captured the particularly nice result shown in Figure 6. This meteor has a (not yet identified) molecular band with mission Q-branch in an early part of its trajectory, where the metal atom lines are still weak.

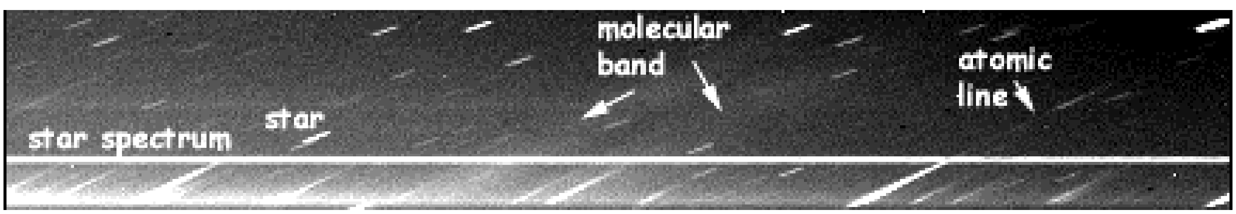

Figure 6 - Cooled CCD spectrum of a meteor in the blue with a newly identified molecular band emission (courtesy Peter Jenniskens and Emily Schaller).

Finally, Jiri Borovicka reports that the Ondrejov video spectrometer detected at least 130 low resolution meteor spectra of various qualities during the first 90 minutes of observation, which included the 4 UT peak. This completes homogeneous material of Leonid video spectra taken with the same camera in 5 different years (1998-2002). Shinsuke Abe of ISAS recorded about 30 HDTV spectra at ultraviolet wavelengths down to 300 nm, several of high quality. Other results include the first near-IR spectrum of a meteor by Mike Taylor and Kim Nielsen of Utah State University (DC-8), the second detection of persistent train emission at mid-IR wavelengths from FISTA (George Rossano, Aerospace Corporation), continuous coverage of airglow and upper atmosphere molecules by the University of East Anglia (John Plane and Alfonso Saiz) and the University of Bremen teams (Armin Kleinboehl and Holger Bremer). The University of East Anglia cooled slit-spectrograph was pointed at three persistent trains, one of which moved astonishingly rapid in upper atmosphere winds.

3.3 Dust collection

Until now, only two particles of questionable origin were captured during Leonid meteor storms by a weather balloon in 1999. At the time of writing, Frans Rietmeijer and Melissa Pfeffer report having found 150 (and counting) particles on the storm-night dust collector. It is not clear yet if any of these are Leonid meteoroids until other collectors are examined and the composition of the particles has been analyzed. Many of these will be volcanic aerosols. However, at least one unquestionably extraterrestial, but non-Leonid, fluffy aggregate particle, and one spherule, were collected on the way over from Omaha to Spain.

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